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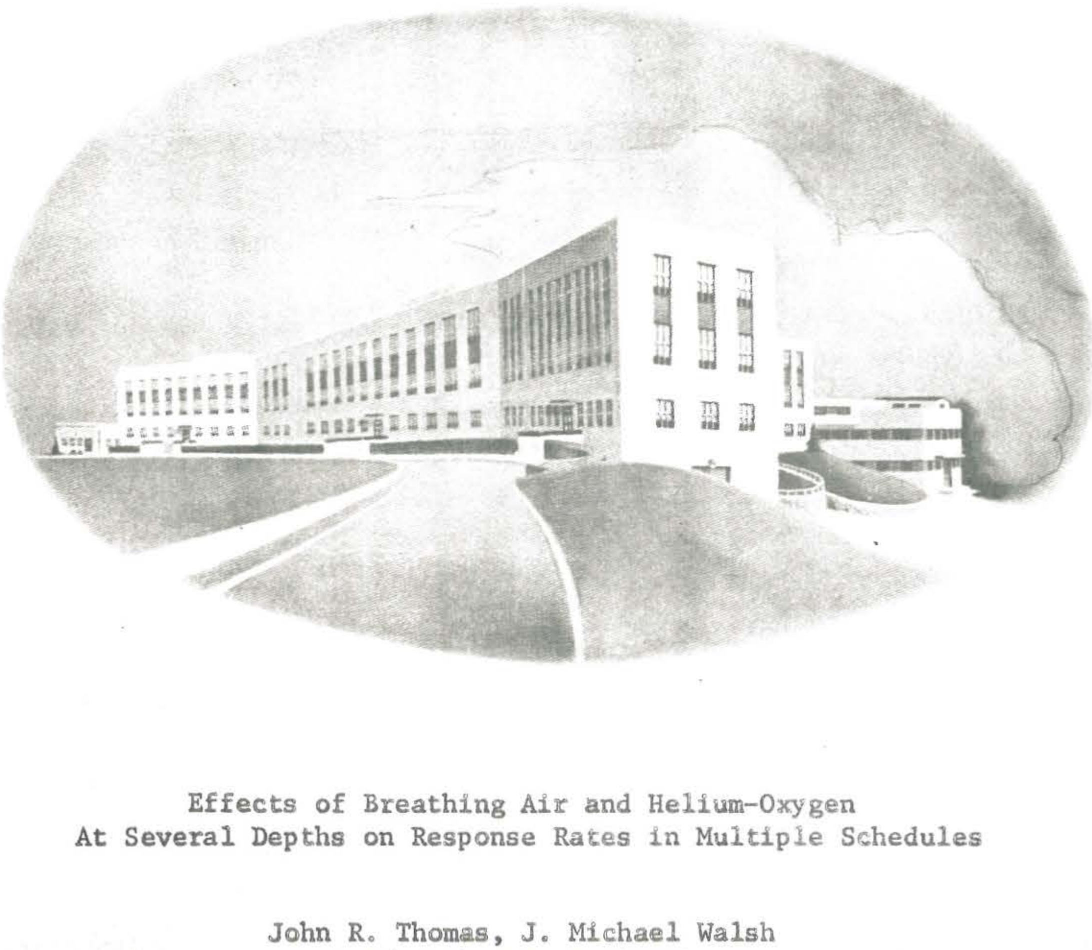

Effects of Breathing Air and Helium-Oxygen At Several Depths on Response Rates in Multiple Schedules

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and Arthur J. Bachrach

Project MF12.524.004.7007D

Research Report No. 1

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AT SEVERAL DEPTHS ON RESPONSE RATES IN MULTIPLE SCHEDULES

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ABSTRACT

Albino rats, trained on a multiple fixed-ratio (FR), differential reinforcement of low rate (DRL) schedule for food reinforcement were repeatedly exposed to increased pressure (equivalent to 100, 200, and 300 feet of sea water) breathing compressed air or an 80% helium-20% oxygen mixture (heliox). Response rates on the two schedules were less disrupted when the heliox mixture was used, although decrements in performance were still observed. Repeated exposure to the same depths produced some behavioral adaptation to pressure effects. Differential rate changes on the two schedules under hyperbaric conditions were observed as a function of schedule contingencies.

KEY WORDS

Hyperbaric animal research

Operant conditioning

Hyperbaric pressure

Multiple schedules

Helium

Compressed air

Adaptation

Hyperbaric performance

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Investigations of the effects of increased pressure on performance have yielded conflicting information, [5,7,14,15,16] but in general a decrement in performance is predictable. Although the tasks and measurement procedures have varied widely, comparisons between compressed air and a helium-oxygen breathing mixture under hyperbaric pressure have indicated less change or decrement in performance with helium-oxygen.[2,3,4,8,9,10,11] Presumably this decrement is due to the substitution of helium for nitrogen in air.

The present study was designed to assess independently the effects of depth and breathing mixtures (air and 80% helium-20% oxygen [heliox]) and to systematically evaluate their interaction on an ongoing, maintained, complex behavioral schedule. Rate of responding on the complex schedule was employed as the measure of performance change under the hyperbaric conditions. Similar behavioral techniques capable of providing a continuous on-line analysis of behavior have recently demonstrated they can be a valuable methodological tool to assess changes and decrements in hyperbaric performance.[12,18,19]

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This experiment was conducted according to the principles set forth in the "Guide for Laboratory Animal Facilities and Care" prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences, National Research Council.

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METHOD

Subjects

The subjects were four male albino rats (NMRI-0, Sprague Dawley derived) maintained at approximately 80% of their free feeding weight.*

Apparatus

The basic apparatus was a rat cage containing two response levers mounted on the front wall which the rats were trained to press to produce a food pellet. A food hopper was mounted between the two levers and was connected to a pellet feeder located behind the response panel. A red stimulus light was mounted above the right response lever and a blue stimulus light was mounted above the left response lever. A white house-light was mounted on the top center of the response panel. (The dimensions and specifications of the cage are in the Appendix.) During training and most baseline control sessions the cage was placed inside a sound-attenuated, air-tight enclosure.

All dive sessions and auditory control sessions were performed with the cage placed inside a steel hyperbaric chamber. The hyperbaric chamber can withstand internal pressures of 1,000 pounds per square inch (psi). (Specifications of the chamber appear in the Appendix.)

Programming of the experimental sessions was accomplished by a system of solid-state digital logic modules connected via cables to the rat cage. Data were recorded automatically on electromechanical counters and on a cumulative recorder. The two gas mixtures used in the study

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*Weights are shown in Table 2, p. 7.

were compressed air (nitrogen 78.1%, oxygen 20.9%, argon 0.9%, carbon dioxide 0.03%, other rare gases 0.003%) and heliox (80% helium, 20% oxygen).

Procedure

Subjects were run in the experiment seven days a week. The experimental sessions were approximately 1 1/2 hours in duration. Each subject was initially trained to press the levers to produce a single 45 mg food pellet delivered in the food hopper. The rats were then trained to respond on a complex reinforcement schedule technically known as a multiple fixed-ratio (FR), differential reinforcement of low rate (DRL) schedule.[13] Under this complex schedule, two simple schedules of reinforcement alternate with each other.

When the red stimulus light above the right lever was illuminated and the houselight was off, a fixed ratio (FR) schedule was in effect. On this schedule the rat was required to depress the right response lever twenty times (FR 20) in order to produce a food pellet. This schedule usually generates a high and rapid rate of responding. When the blue light above the left lever was illuminated and the houselight was on, a differential reinforcement of low-rate schedule (DRL) was in effect. This is a schedule requiring spaced responding. On the DRL schedule a food pellet was produced by a single response on the left lever which followed a preceding lever press on that lever by at least 18 seconds, but not more than 24 seconds. This schedule is actually a DRL schedule with a limited-hold specification. The limited hold (LH) allows a

specified limited time period when a reinforcement is available. This schedule usually generates a low and steady rate of responding.

During an experimental session the FR and DRL schedules alternated with each other. Each schedule was in effect for a variable period of 1, 2, or 3 minutes. A blackout period of 30 seconds, during which all lights in the cage were off and responses had no programmed consequences, occurred between the termination of one schedule and the beginning of the other.

After stable baselines were obtained on the multiple schedule each subject was exposed to a number of auditory control sessions in the hyperbaric system. Compressed air was allowed to flow into the chamber for a duration equivalent to that of an experimental dive. All chamber valves were left open so that ambient pressure was maintained and only noise level was manipulated.

Subjects 9 and 10 were exposed repeatedly to a hyperbaric pressure equivalent to 200 feet of sea water (89 psig) under compressed air. Rat 9 was exposed to 200 feet for four dives and Rat 10 for three dives. Eight to ten control sessions occurred between each dive. Rat 9 was then exposed to hyperbaric pressure equivalent to 100 feet (44 psig) and 300 feet (133 psig) of sea water under compressed air.

Rats 12 and 15 were exposed to hyperbaric pressures of 200 feet and 300 feet with both compressed air and heliox. Rat 12 was additionally exposed to 100 feet under both air and heliox. The order of exposure to the depths and gas mixtures for the subjects is shown in Table 1.

TABLE 1

Order of Exposure to Depths and Gas Mixtures

for the Subjects

Rat 9	Rat 10	Rat 12	Rat 15
200 ft. - Air	200 ft. - Air	200 ft. - HeO_2	200 ft. - HeO_2
200 ft. - Air	200 ft. - Air	200 ft. - Air	200 ft. - Air
200 ft. - Air	200 ft. - Air	100 ft. - Air	300 ft. - HeO_2
200 ft. - Air		100 ft. - HeO_2	300 ft. - Air
100 ft. - Air		300 ft. - HeO_2	
300 ft. - Air		300 ft. - Air	
200 ft. - Air			

HeO_2: 80% helium-20% oxygen mixture (heliox)

The duration of the experimental dives varied from 1 1/2 to 2 hours, depending on depth. Compression rate was approximately 10 feet per minute. Time at depth was one hour. Decompression rate was kept close to 10 psi per minute with 3-minute stops at 80, 59, 34, 14, and 6 psig as appropriate for particular depths.

RESULTS

Control Baselines

All four subjects performed appropriately on the multiple schedule under baseline conditions. Appropriate schedule performance was under the control of the discriminative stimuli associated with each schedule. The subjects exhibited a high and constant rate of responding, following an initial pause, on the FR schedule when the red light above the right lever was illuminated. A low rate of responding occurred on the DRL schedule when the blue light above the left response lever was on.* The auditory control sessions indicated that the noise associated with gas flow in the chamber had little effect on the baseline performance. The average rate of responding (responses/min) during baseline sessions is presented in Table 2 for the four subjects. Unless otherwise specified the data presented in this report are in terms of percent of change from control baseline rates.

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*Performance on the multiple FR-DRL schedule is illustrated in the top half of Figure 3, Page 12, which shows a portion of a cumulative record from a control baseline session for Rat 9.

TABLE 2

Average Response Rates (Responses/min)

During Baseline Sessions for the Subjects

Subject	Weight (grams)	FR	DRL
Rat 9	525	49.6	6.3
Rat 10	540	105.4	7.7
Rat 12	420	50.0	10.4
Rat 15	500	102.5	8.9

Repeated Dives to 200 Feet

The effects of repeatedly exposing Rats 9 and 10 to a hyperbaric pressure depth of 200 feet are shown in Figure 1. The major result was that the direction of the changes from control rates for the first several exposures was dependent on the schedule of reinforcement. Response rates on the FR schedule were decreased compared to control rates as a function of exposure to hyperbaric conditions, whereas response rates on the DRL schedule were increased above control response rates.

A second finding was that subsequent exposure to the same depth apparently produces behavioral adaptation. This is shown in terms of subsequent dives revealing less disruption (change from control rates) for the FR and DRL performance. The greatest decline in FR response rates for both subjects occurred on the initial exposure to 200 feet with subsequent exposures producing less and less of response rate decline. This may be clearly seen in Figure 1. Similar systematic changes with repeated exposures were not so apparent for the DRL schedules. However, the data presented for the DRL in Figure 1 is based on an average overall response rate which disguises the rather precise timing behavior produced by this schedule. Presenting the data for the DRL schedule in another manner, which emphasizes the temporal patterning of responding, clearly shows an adaptation over subsequent dives. Figure 2 shows the DRL data for Rat 9 presented in this fashion. The figure shows inter-response

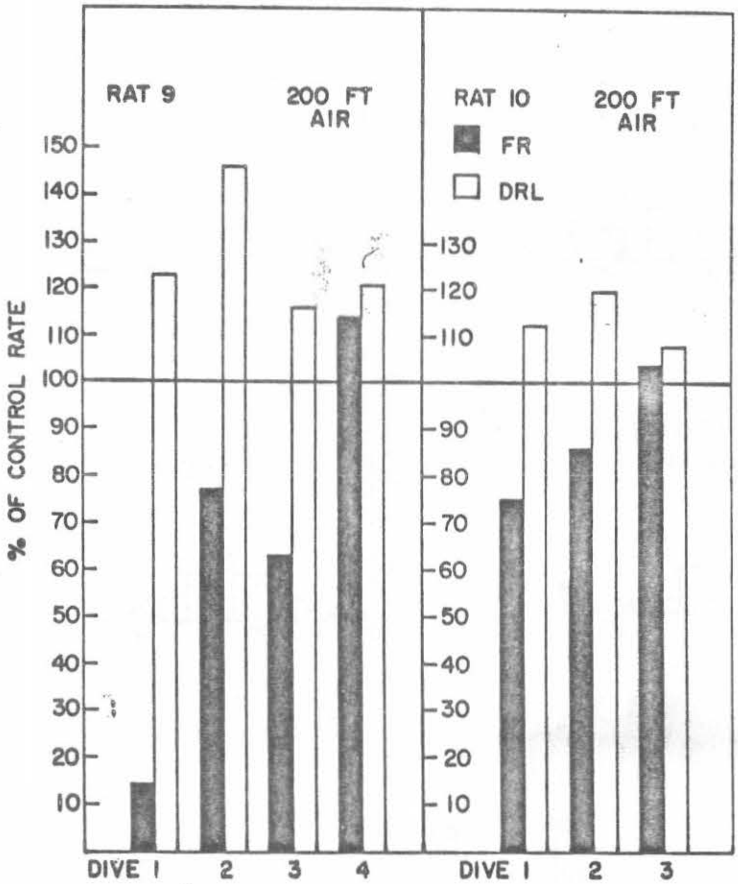

Figure 1. Percent of control response rates on the multiple FR-DRL schedule with repeated exposures to 200 feet breathing air for Subjects 9 and 10.

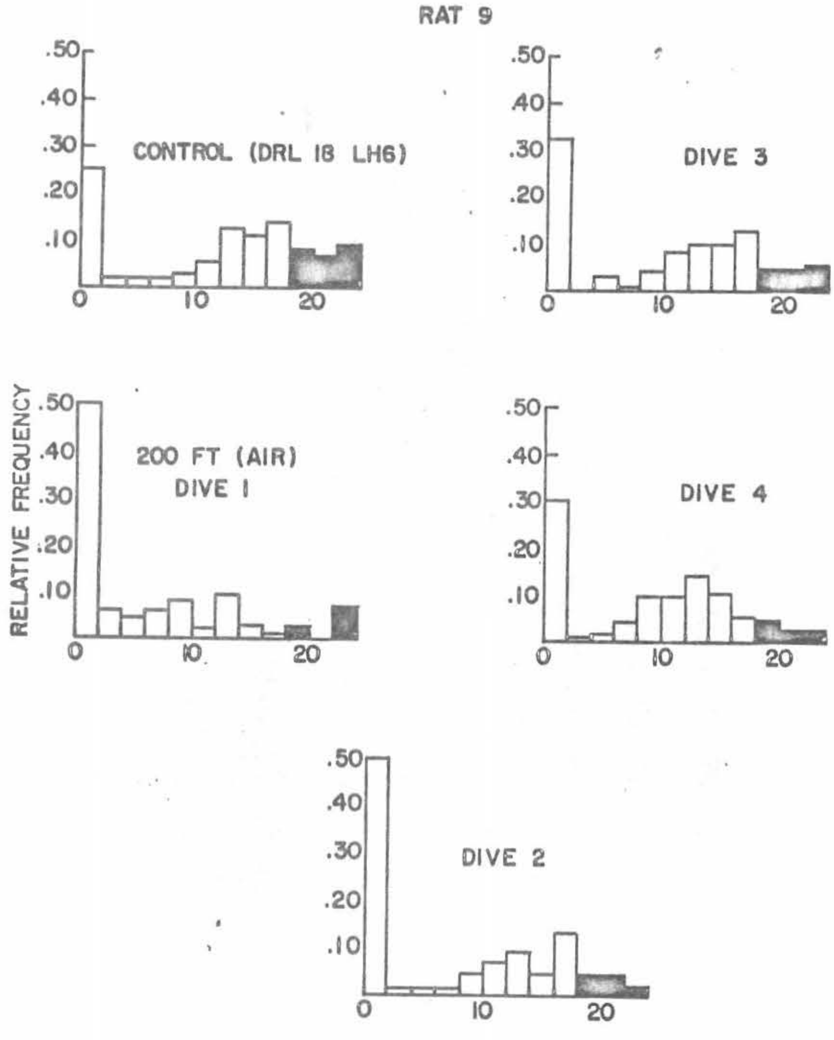

Figure 2. Inter-response time (IRT) frequency distributions of the DRL schedule for control and four repeated exposures to 200-feet breathing air for Subject 9.

time (IRT) frequency distributions for baseline control and the four dive sessions. The control distribution shows a large number of responses occurring between 0-2 seconds, followed by a drop in frequency to almost zero, and then a gradual increase to the point where the shortest IRT that can produce a reinforcement (18 seconds) occurs, followed by a decline. This essentially shows the existence of an established temporal discrimination. In the IRT distribution for the initial dive to 200 feet, the frequency of responding doubled in the 0-2 second time interval and the distribution of responses generally shifted toward the short intervals. The IRT distributions for subsequent dives show that with each exposure to the hyperbaric conditions less disruption of the temporal discrimination occurs.

Figure 3 shows cumulative response records for Rat 9 from portions of a control session and from an exposure to 200 feet. A comparison between A and B shows the increase in DRL performance above control; of particular interest is the high ratio-like burst of responding at B. Similar changes can be seen at D as compared to C. The decrease in FR response rates can be seen most dramatically at F as compared to E, where for one schedule component responding is almost completely absent. In general, the decrease in FR rates was due to a lower rate of responding rather than a complete change in pattern of responding.

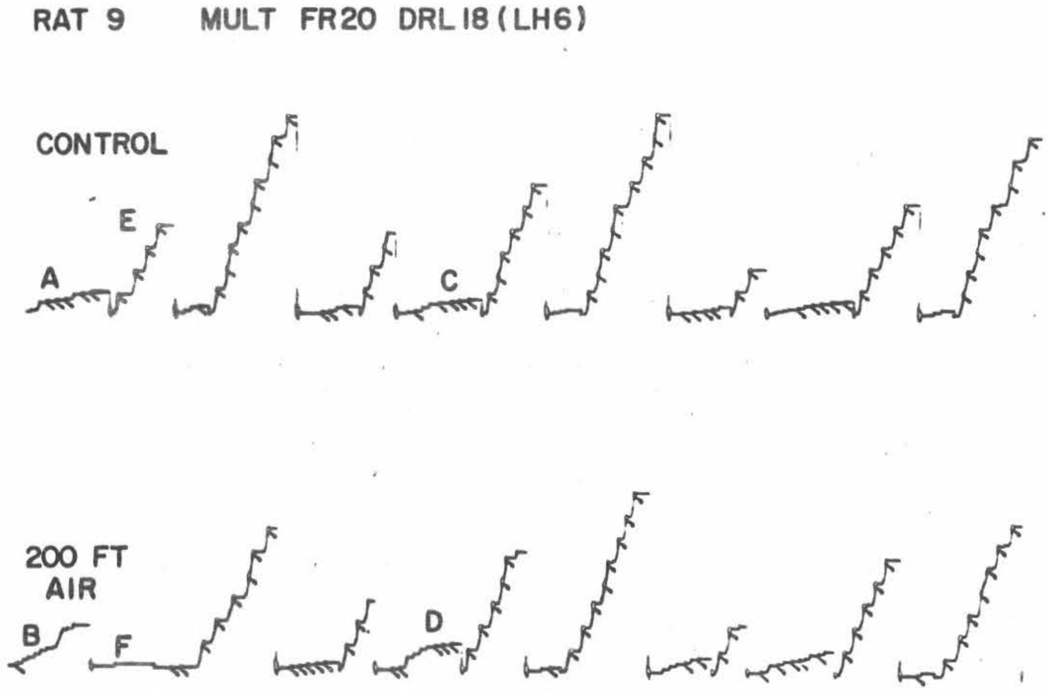

Figure 3. Segments of cumulative response records for Subject 9 on the multiple FR-DRL schedule for control (A) and 200-foot (B) sessions. Downward pips of the recording pen indicate reinforcements. The recording pen resets to baseline at the end of the interval for each schedule.

Exposure to Several Depths and Gas Mixtures

Figure 4 shows the changes on the multiple FR-DRL schedule for Rat 9 for three depths with compressed air. The differential rate effects (decrease in FR rates, increase above control for DRL rates) occurred at both 100 feet and 200 feet, with perhaps more effects at 200 feet. Exposure to a depth of 300 feet breathing air almost completely eliminated responding on both schedules.

Figure 5 shows the changes on the multiple schedules for several depths and with the two different gas mixtures for Rats 12 and 15. For these two subjects there appears to be an overall decrease in performance with deeper depths. The differential rate effects previously noted for the other subjects may be seen for Rat 12. Rat 15 does not clearly show this effect.

The major finding in comparing the effects of air with heliox for the 200- and 300-foot depths is that response rates are lower for both FR and DRL schedules under air than under heliox. This is probably more apparent at the 300-foot depth. Portions of cumulative response records for Rat 12, showing performance under air and heliox conditions at 200 and 300 feet, are presented in Figure 6.

DISCUSSION

Rate of responding on complex schedules of reinforcement under hyperbaric conditions was shown to change differentially depending on the contingencies of reinforcement. High rates of responding generally decreased under hyperbaric exposures while low rate behavior increased.

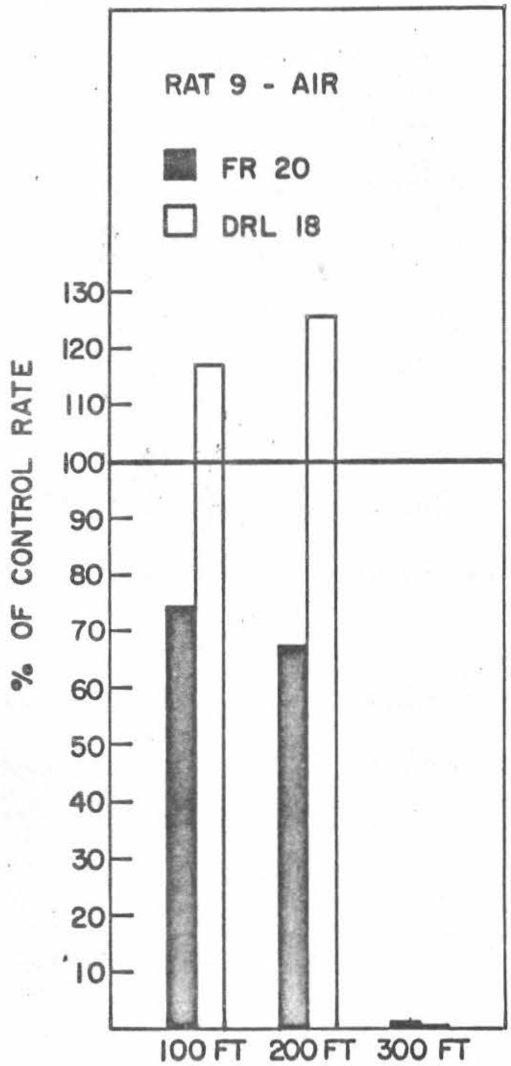

Figure 4. Percent of control response rates on the multiple FR-DRL schedule for 100, 200, and 300 feet breathing air for Subject 9.

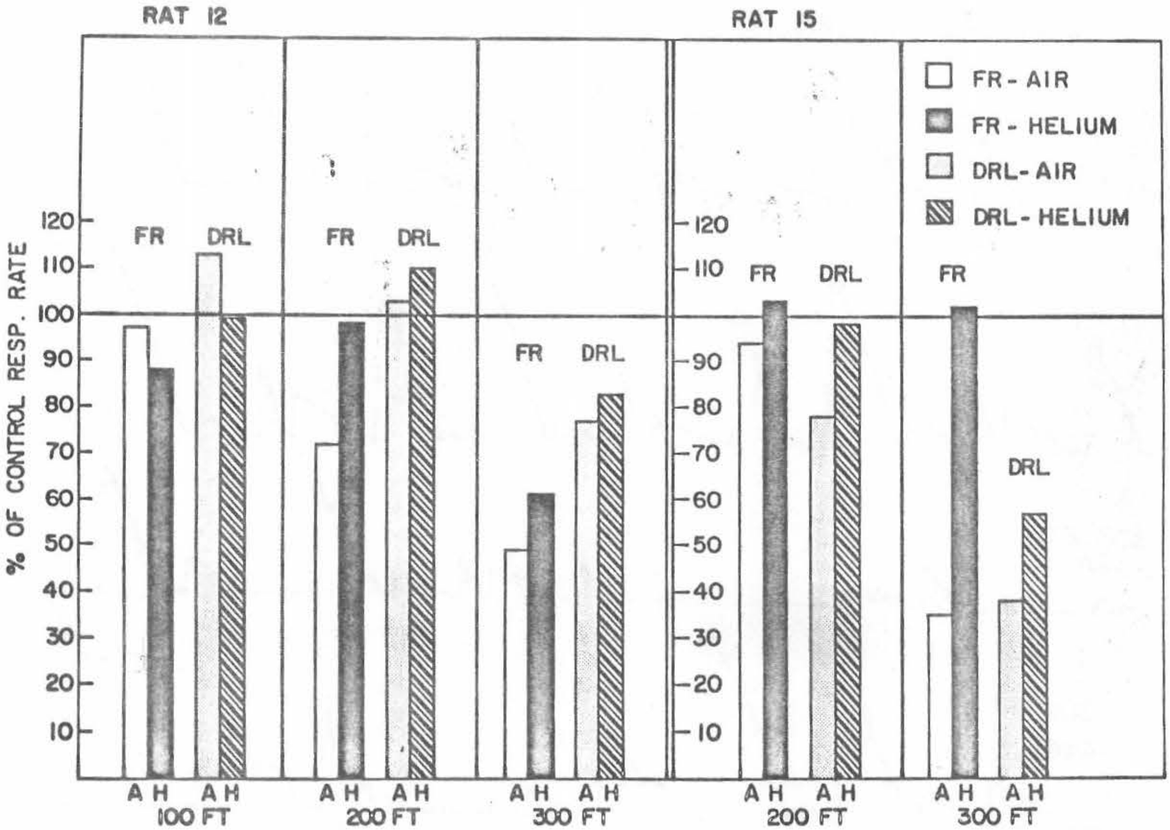

Figure 5. Percent of control response rates on the multiple FR-DRL schedule at several depths under air and heliox for Subjects 12 and 15.

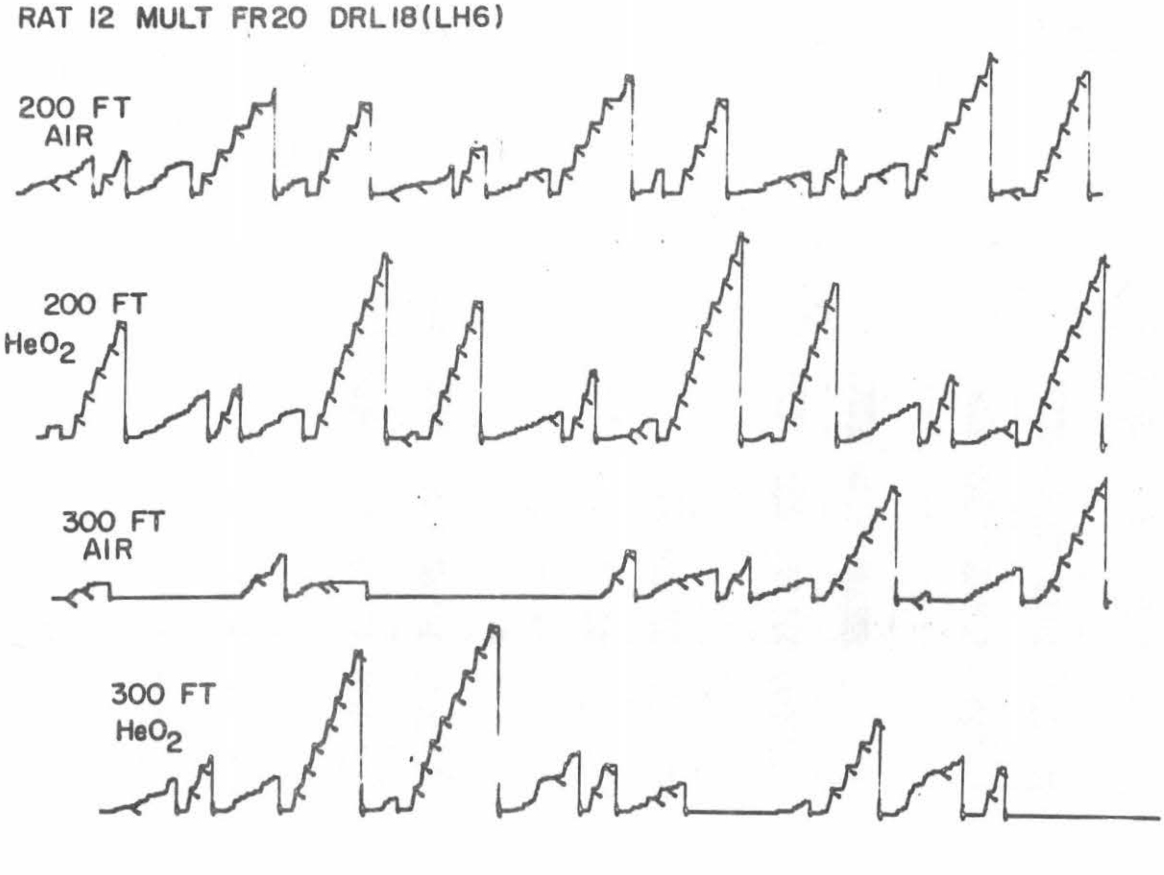

Figure 6. Segments of cumulative response records for Subject 12 on the multiple FR-DRL schedule at 200 and 300 feet under air and heliox.

This differential rate change has been reported with a number of pharmacologic agents[17] and suggests a behavioral similarity between gas effects under pressure and the effects of several pharmacological variables which heretofore have been unrecognized and unexplored.

Adaptation to the effects of pressure, which has often been subjectively reported,[1] appears to be substantiated with quantitative evidence. With each additional exposure to hyperbaric pressure performance on both schedules of reinforcement more closely approximated baseline rates. Similar behavioral adaptation under hyperbaric conditions has been previously reported for DRL schedules of reinforcement.[16] This type of behavioral adaptation also shows similarities with behavioral tolerance that is developed under chronic drug regimens.[17]

The present data indicate that performance decrements due to pressures are certainly visible at depths as shallow as 100 feet. At depths of 300 feet the behavioral disruptions were severe and a significant decrease in response rates on both schedules resulted. This was particularly true with compressed air as the breathing mixture.

Where air and helium-oxygen breathing mixtures were compared over different depths the results indicate that the behavioral change or disruption is somewhat lessened when the organism is breathing the heliox mixture. This finding is in accord with previous work using a variety of measures.[2,3,4,8,9,10,11] The lessened disruptive effects of heliox is theoretically attributed to the replacement of nitrogen in the air mixture by helium, therefore removing the narcotic effects of nitrogen.

Bennett states that "...at 10 ata (300 feet) compressed air is very narcotic, whereas a 20-80% oxygen-helium mixture is not."[6] However, the present data indicate that performance decrements also occur with helium-oxygen mixtures although the effects are less than with compressed air.

APPENDIX

Specifications of Apparatus and Chamber

The basic operant apparatus used in this experiment is a Harvard Instrument Company rat cage (8 1/2 inches wide, 9 1/2 inches long, and 8 inches high) made with aluminum front and back panels and perforated plexiglass sides and top. The floor of the box is comprised of 18 (1/16-inch) stainless steel rods, with a stainless steel drop pan 2 1/4 inches below the grid. Two Lehigh Valley mouse levers are mounted on the front panel 1 inch above the grid and 1 inch from either of the side panels. A brass food hopper (Scientific Prototype) is mounted 1/2 inch above the grid and in the center of the panel equidistant from each of the levers. The food hopper is attached by a short rubber tube to a Gerbrands pellet feeder which dispenses 45 mg Noyes pellets as reinforcement. Mounted above each lever and the food hopper are stimulus lights with interchangeable colored plastic covers. The entire apparatus (box, feeder, etc.) is mounted on a sheet metal base with all electrical connections to the apparatus terminating on a blue ribbon connector mounted on the end of the sheet metal base.

During training and most baseline sessions, the apparatus was mounted on steel slides inside a BRS-Foringer rat housing which is a sound-reducing air-tight enclosure, 18 1/2 inches high x 29 inches wide x 16 inches deep, with a filtered ventilating fan.

All of the pressure runs and some noise control sessions were conducted with the basic apparatus mounted on a set of slides inside a Bethlehem hyperbaric chamber. The chamber is cylindrical with internal dimensions of 42 inches in length and 18 inches in diameter. The chamber can withstand internal pressures of 1,000 pounds per square inch (psi) which is comparable to a depth of 2,245 feet of sea water. The chamber is penetrated with several threaded openings for pressure-fitted connectors to the gas supply and the various programming instrumentation associated with the test apparatus. Across the upper inside surface of the chamber is a metal plate with heating and cooling coils which are thermostatically controlled to maintain constant temperature (24-26°C).

REFERENCES

1. Adolfson, J.: Deterioration of mental and motor functions in hyperbaric air. Scand. J. Psychol. 6:26, 1965.

2. Baddeley, A. D.: The efficiency of divers breathing oxy-helium. Ergonomics 10:311, 1967.

3. Baddeley, A. D., and N. C. Flemming: The relative efficiency at depth of divers breathing air and oxy-helium. Report for the Underwater Research Association, Great Britain, 1965.

4. Bennett, P. B.: The effects of high pressures of inert gases on auditory evoked potentials in cat cortex and reticular formation. Electroenceph. clin. Neurophysiol. 17:388, 1964.

5. Bennett, P. B.: The aetiology of compressed air intoxication and inert gas narcosis. London: Pergamon Press, 1966.

6. Bennett, P. B.: Inert gas narcosis. In (Eds.) P. B. Bennett and D. H. Elliott The physiology and medicine of diving and compressed air work. pp. 155-182. London: Bailliere, Tyndall, and Cassell, 1969; Baltimore, Md.: Williams and Wilkins Co., 1969.

7. Bennett, P. B.: Measurement and mechanisms of inert gas narcosis. J. Occup. Med. 11:217, 1969.

8. Bennett, P. B., K. N. Ackles, and V. J. Cripps: Effects of hyperbaric nitrogen and oxygen on auditory evoked responses in man. Aerospace Med. 40:521, 1969.

9. Bennett, P. B., and A. Glass: Electroencephalographic and other changes induced by high partial pressures of nitrogen. Electroenceph. clin. Neurophysiol. 13:91, 1961.

10. Bennett, P. B., and A. J. Hayward: Relative decompression sickness hazards in rats of neon and other gases. Aerospace Med. 39:301, 1968.

11. Bennett, P. B., E. C. Poulton, A. Carpenter, and M. J. Catton: Efficiency at sorting cards in air and a 20 percent oxygen-helium mixture at depths down to 100 feet in enriched air. Ergonomics 10:53, 1967.

12. Burns, J. D.: Hyperbaric gas effects on critical flicker frequency in the rhesus monkey. Physiology and behavior 7:151, 1971.

13. Ferster, C. B., and B. F. Skinner: Schedules of reinforcement. New York: Appleton-Century-Crofts, 1957.

14. Jennings, R. D.: A behavioral approach to nitrogen narcosis. Psych. Bull. 69:216, 1968.

15. Lambertsen, C. J.: (Ed.) Underwater physiology. Proceedings of the third symposium on underwater physiology sponsored by the Committee on Undersea Warfare of the National Academy of Sciences, National Research Council and The Office of Naval Research in Washington, D. C., 23, 24, and 25 March 1966. Baltimore: The Williams and Wilkins Co., 1967.

16. Lambertsen, C. J., and L. J. Greenbaum, Jr.: Proceedings: Second symposium on underwater physiology, Washington, D. C., February 25-26, 1963. Publication 1181, NAC-NRC, Washington, D. C., 1963.

17. Thompson, T., and C. R. Schuster: Behavioral pharmacology. Englewood Cliffs, N. J.: Prentice Hall, 1968.

18. Walsh, J. M., and A. J. Bachrach: Timing behavior in the assessment of adaptation to nitrogen narcosis. Naval Medical Research Report No. 2, Bethesda, Md., July 1971.

19. Walsh, J. M., A. J. Bachrach, J. R. Thomas, and D. R. Thorne: Differential changes in response rates under hyperbaric conditions. Science, in press.